Software Development for the Analysis and Design of Ship Berthing Structures

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***Abstract*- The construction and maintenance of berthing structures are very expensive and therefore the most economic design should be adopted. To arrive at an economic design the structural engineer has to repeat the design for different alternatives for all loading conditions. To minimize his effort a computing tool has become necessary.**

Software BESTDESIGN has been developed using the computer language Visual Basic and the Database MS-Access for the analysis and design of ship berthing structures. The software can be used for the analysis and design of new berthing structures and can also be used for obtaining the design aspects while reconstructing an existing structure.

The software developed was tested with the requirements at Cochin Port. Cochin Port Trust is the authority of a number of ship berthing structures. Some of them are to be reconstructed and there are new projects involving the construction of new ship berths or the extension of existing berthing structures.

I. Introduction

A. Berthing Structure

The berthing structures are constructed for the berthing and mooring of vessels to enable loading and unloading of cargo and for embarking and disembarking of passengers, vehicles etc. The planning and design of berthing structures depend on various factors.

B. Planning of the Berthing Structure

A berthing structure is a capital intensive project, thereby, optimum use of both space and capital becomes imperative. This means that proper planning of the various units of the structure, for the present and an optimistic future demands, is necessary. Berthing structures world over suffer from congestion or inflexibility due to short comings in planning or due to wrong estimate of the traffic and or land requirement. Planning a berthing structure should satisfy certain basic objectives.

1) The berthing structure should be planned to incur minimum capital expenditure to handle the expected traffic.
2) Planning of various systems should keep the operating costs to a minimum.
3) Planning should include a fair degree of flexibility to incorporate future expansion programmes.
4) Planning should ensure free, smooth traffic with adequate road/rail access facilities.
5) The capacity of a berthing structure is usually measured in terms of containers/passengers that can be handled by the terminal per year.

Berthing structures vary widely in

1. Configuration, layout, container handling technology user requirements and operating rationale.
2. Berth requirements depending upon the type of shipping service, ship types and sizes to be served.
3. Land access, rail, road service requirements.

In particular planning of a berthing structure means establishing the number of berths, berth length, the area required for storing containers until they are discharged, area requirement for parking both terminal and highway trailers and the areas for administrative and maintenance operations.

To arrive at an economic design of a berthing structure the structural engineer has to repeat the design for different alternatives for all loading conditions. To minimize his effort a computing tool has become necessary. The software developed can be used for the analysis and design of new berthing structures and can also be used for obtaining the design aspects while reconstructing an existing structure.

II.General Structural Configuration

A. Location

The location for berthing structures was decided based on a number of factors such as easy accessibility for the ships, availability of sufficient draft throughout the year, favourable meteorological and wave hydrodynamic conditions. The last factor plays a major role in determining the magnitude of forces acting on the structures.

B. Classification

After having decided about the location of the berthing structure, the type of the structure to be constructed needs to be examined. The factors controlling the selection of the type of structure are the flow conditions and the soil properties.

Berthing structures can be classified as wharfs and piers.

1) Wharf - A wharf is a berthing structure parallel to the shore. It is generally contiguous with the shore, but may not necessarily be so.

Pier - A pier is a berthing structure which projects out into water. A pier does not necessarily need to run perpendicular

DOI: 01.IJTUD.01.01.22

to the shoreline but may project under any angle. It may also be connected with the shore by a trestle and may thus be T or L shaped.

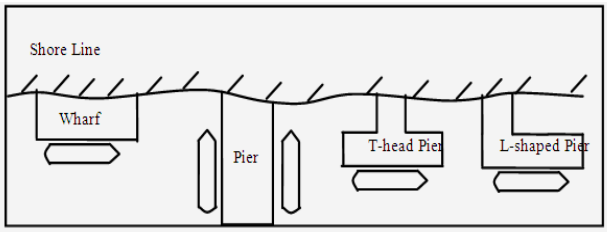

Fig.1. Different Types of Berthing Structures

C. Number of Berths

The number of berths required in the terminal largely depends upon the traffic to be handled in terms of number of ships to be serviced and their arriving pattern. However, initial investment also plays a major role while planning a new terminal.

D. Length of Berth

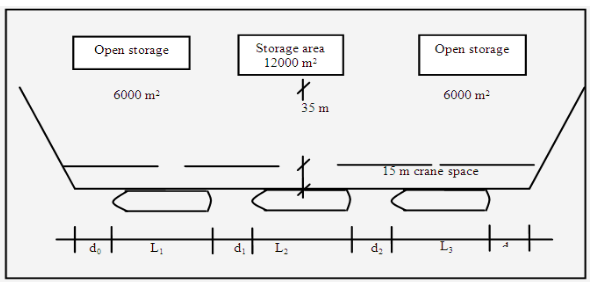

Fig.2.General Wharf Layout

The berth length to be provided depends upon the function of the terminal and the size and the types of ships that are likely to call at the port.

Berth length required for main line vessels is 275 + 25 = 300 m

Berth length required for feeder vessels is 150 + 50 = 200 m

E. Area of Berth

Berthing area should be based on the length and breadth of the largest size of ship using the berths. Berthing area is the area in front of the berthing structure required for berthing vessels and also accommodates the service vessels. Length required for berthing a vessel and its surging movements due to wave and currents is generally specified as 10% of ships length, subject to a minimum of 15m. as in fig4.2, d1 should not be less than (L1+L2)/20 and d_2 >= (L2+L3)/20 where there are solid obstructions, the safe distance of d_0 = 25 – 30 m is allowed. The width of the berthing area should be 1.15 B + b where B is the beam width of the design vessel and b is the width of the attending craft.

F. Draft alongside Berth

The third generation container vessels have a draft of 12.5 m. Hence a depth of 13.5 m has to be maintained alongside the quay during all conditions allowing sufficient depth for various allowances.

Depth at the berth should be 10% in excess of maximum loaded draft of design vessel to allow for silting and vertical motion.

G. Apron Width

Apron width a pier is dependent on the type of equipment used for loading and unloading operations. The apron width is decided based on the facilities provided.

TABLE 1
STANDARD APRON WIDTH

Sl.no	Facilities provided	Apron width (m)
1	one way road traffic	6.5
2	two way road traffic	8.0
3	modern cargo berths	15
4	container berths	40

The width of the berth will mainly depend on space requirements of heavy duty ship to shore cranes which must have mobility throughout the berth length. The requirements, for the width of apron varies with the distance from berthing line to the first rail track of the gantry crane and with the back reach of the crane. Dimensions of the container cranes may vary accordingly to the design and capacity of the crane. Required width of the apron for typical container crane is 2 to 4 m for the distance from water front to the first rail, 20 to 35 m for the track width of the crane and 8 to 16 m for back reach, making a total of 30 to 55 m towards back.

H. Deck Elevation

Deck elevation is fixed at or above the highest high spring water level plus half the wave height near the berth plus a free board of 1m. The maximum distance of quay edge inclusive of fixed fenders from the outer track of the crane is about 2.65m. This is the optimized distance considering the conflicting requirements of not being too close to cause a collision between crane and ship ad not too far to put a limitation on the reach of the crane arm from loading and unloading of vessel.

I. Navigation Channel- Turning Circle

Dimensions of turning circle are dependent on the prevailing intensity of wind, current and the power of tugs available for assistance. The following criteria may be followed in either case for calculating the radius of the circle:

i) Without tug assistance - 1.7 l
ii) With tug assistance - 0.85 L

The third generation ships will have a draft of 12.2 m. Hence an navigational channel which can accommodate these ships is necessary with a minimum depth of 13.5 m.

J. Stacking Area Requirement

The area required for storage of container within the terminal depends on the following factors:

1) Throughput expected to pass through the terminal per annum.

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2) Dwell time of containers within the terminal. This is the average time a container would spend in the yard after import and before re-export in a transit terminal.

3) The type of container handling equipment used for stacking.

4) Average stacking height: Containers are not stacked to the maximum height in all the slots within the stacking area. This is required to enable the handling equipment to pick up the lower containers in the stack for discharge. Furthermore, containers need to be segregated by destination, weight class, and direction of travel sometimes by types and often shipping line or service. Hence there is always a ratio between the average stacking height and maximum stacking height.

5) Peaking factor: This is the ratio of the peak traffic to the average traffic, usually taken between 1.3 to 1.4.

6) Ratio of working slots: All the slots provided on the ground cannot be available for stacking due to various reasons. The ratio of working slots to overall slots is usually taken as 0.8.

K. Area Requirements for other Facilities

1) Container Freight Station: Although transit terminal does not require establishment of CFS as the containers are not moved into the mainland through the terminal. Hence stuffing and destuffing operations are non-existent. However, as a emergency measure for custom checking etc, a CFS of a smaller capacity has to be provided. A CFS of area measuring 4 hectares may be provided.

2) Trailer storage - 1 hectare

3) Equipment parking - 1 hectare

4) Road vehicle parking -1.5 hectares

5) Rail marshalling yard -2.5 hectares

6) Internal roadways - 2.5 hectares

7) Administrative area - 1 hectare

8) Maintenance and repair area- 1.5 hectares

9) Container repair area - 1 hectare

III. Loads On The Berthing Structures

All possible loads on the berthing structure were calculated as per IS4651-part III-Loading, the Code of practice for planning and design of ports and harbours.

A. Dead Load

Dead loads consist of the weight of all components of the structure as well as the weight of all permanent attachments. The DL of a port related marine structure constitutes a relative small percentage of the total load acting on the structure.

B. Vertical Live Load

Vertical LL consist of the weight of all movable equipments on the structure.

TABLE II
TRUCK LOADING AND UNIFORM VERTICAL LIVE LOAD

Sl.no	Function of berth	Truck loading (IRC Class)	Uniform vertical LL (T/m^2)
1	Passenger berth	B	1.0
2	Bulk unloading and unloading berths	A	1.0 to 1.5
3	Container berths	A or AA or 70 R	3 to 5
4	Cargo berths	A or AA or 70 R	2.5 to 3.5
5	Heavy cargo berth	A or AA or 70 R	5 or 6
6	Small boat berth	B	0.5
7	Fishing berth	B	1.0

C. Berthing Load

When an approaching vessel strikes a berth a horizontal force acts on the berth. The magnitude of this force depends on the K.E that can be absorbed by the fendering system. The reaction force for which the berth is to be designed can be obtained and the deflection reaction diagram of the fendering system chosen. These diagrams are obtainable from the fender manufacturers.

The Kinetic Enery E, imparted to a fendering system, by a vessel moving with velocity V m/s is given by

$$\frac{W_D \times V^2 \times Cm \times Ce \times Cs}{2g} \qquad (1)$$

Where W_D = displacement tonnage (DT) of the design vessel in tonnes, v = velocity of vessel in m/s, normal to berthing, g = acceleration due to gravity in m/s^2,Cm = mass coefficient, Ce = eccentricity coefficient, Cs = softness coefficient.

D. Mooring Load

The forces acting on a moored vessel arise from the following sources : winds, currents, wind waves, waves from passing vessels, tidal variations etc. The mooring loads are the lateral loads caused by the mooring lines when they pull the ship into or along the dock or hold it against the forces of wind or current.

The maximum mooring loads are due to the wind forces on exposed area on the broad side of the ship in light conditions.

$$F = Cw\,Aw\,P \qquad (2)$$

Where, F = force due to wind in Kg.,Cw= shape factor, P = windage pressure in kg/m^2 to be taken in accordance with IS875-1964, PII (code of practice for structural safety ofbuildings :- loading standards). Aw= Windage area for the design ship.

E. Current Load

The force per square metre of area produced by sea water impinging on the side of a ship may be computed from the formula:

$$F = w\,v^2/2g \qquad (3)$$

F= force in N/m^2, v= velocity of current in m/s ,d= loaded draft of ship in m,w = unit weight of sea water and g = 9.81m/s^2.

This force may be transmitted to the substructure of the pier either by the ship bearing against the fender system or through the mooring lines.

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F. Wave Load

Waves are primarily caused by the wind on water. The height of a wave is governed by the wind speed, duration and fetch. Waves are negligible in port area.

G. Wind Load

Wind load on the structure was calculated based on IS875-1964 as applicable.

Design wind pressure

$$P = 0.6\ v_z^2 \qquad (4)$$

Where v_z = vb x k1x k2 X k3

H. Earthquake Load

Load on structure due to Earthquake was considered to be,

$$F = \alpha_h\ [DL + 0.5\ LL]\ g \qquad (5)$$

Where α_h =0.04.

I. Load Factors

The various loads to be considered are defined below, along with a general reference to the type of component to which each design applies. Each component of the structure should be analyzed for all applicable stresses, bearing and uplift in the component.

TABLE III
LOAD FACTORS FOR LOAD COMBINATION

Sl. no.	Load type	normal condition	mooring condition	berthing condition
1	Dead load	1.4	1.2	1.2
2	Live load	1.7	1.7	0.2
3	Wind load	1.3	1.3	1.0
4	Current Load	1.3	1.3	1.0
5	Mooring load	-	-	1.7
6	Berthing load	-	-	1.7

J. Load Combinations

1) Dead Load.
2) Live Load.
3) Berthing Force.
   (Berthing angle is only 4° to 6° hence only the transverse component of berthing force is considered for design purpose)
4) Mooring Force at 90°
5) Mooring Force at 45°
6) Mooring Force at 30°
7) Current Force.

(Wharf structures are constructed parallel to the current direction hence only the longitudinal component of current forces are considered for design purpose)

Load Combinations :

i. Load (1+2),
ii. Load (1+2+3)
iii. Load (1+2+4 or 5 or 6)
iv. Load (1+2+3+7)

IV. Analysis And Design

The berth is analysed as a two dimensional structure using BESTDESIGN program (Developed using the Kani's method of Structural Analysis).

The berthing structure may be considered as a concrete frame. The analysis of frames is cumbersome as the frames have a large number of joints which are free to move. If moment distribution is applied to all the joints, the work involved is tremendous. However with certain assumptions it is possible to analyse the frames and get the results which are quite satisfactory from design point of view.

The effect of wind forces and horizontal forces due to seismic effect is to cause vertical forces in columns and moments in all the members. In analysing the frame for the horizontal loads it is assumed that horizontal forces are transferred to joints. Kani's method is adopted for the analysis of frames. This method can be adopted for the analysis and design of frames subjected to both vertical and horizontal loads. The sections are designed for bending moment, shear force and axial force.

A. Design of Deck Slab

The slabs are designed to carry a live load of 3t/m². They are designed as simply supported on all the four edges and spanning two directions. M30 concrete (design mix) and HYSD bars are used. If lx is the length of slab in longitudinal direction and ly the length in transverse direction, check the value of lx/ly. If the ratio is less than 2 then it is designed as a two way slab.

B. Design of Beams

Assume a suitable beam size for a longitudinal as well as a transverse beam. Let 1000mm X 700mm be the size of a transverse beam and 1200mm X 800mm the size of longitudinal beam. The beams are then designed by the limit state method explained in SP 16.

C. Design of Pile

The pile is assumed to be fixed at 8D (D= outer diameter of the pile) below the degree level. Based on the results of the analysis, the piles are designed for the axial forces and bending moments

V. Details Of The Software 'Best Design'

A Software package for the analysis and design of ship berthing structures was developed using the computer language Visual Basic and the database management system MS Access.

The load calculations are done based on the IS4651-1974. Suitable forms are developed to calculate the loads.

The analysis software is developed based on the Kani's method of structural analysis. The Kani's method is suitable for both vertical as well as lateral loads on framed structures.

The design of the slabs, beams and piles are designed as per IS456-2000,SP16 and IS 2911-Part 1/sec II. Suitable forms have been developed to design and draw the required reinforcement in the structural members.

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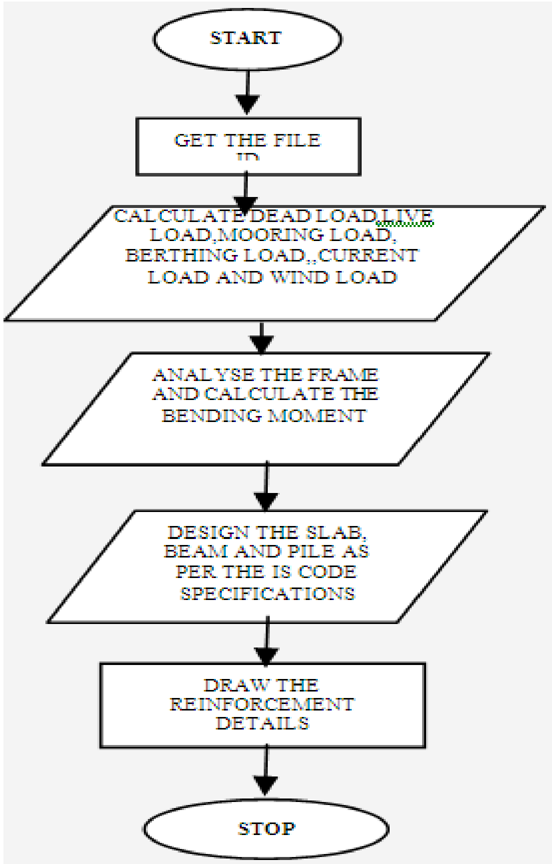

Fig.3.Flow Chart for the Software 'BESTDESIGN'

VI. Case Study Using BestDesign Software

TABLE IV

Sample Design of a Ship Berthing Structure.

STEP NO.	SAMPLE INPUT	SAMPLE OUTPUT	BESTDESIGN FORM NAME
1.	nil	file id no=150	NEW FILE
2.	Wearing coat=0.075 X 24 Slab=0.3 X 25 Beam(transverse)= 0.8 X 2 X 25 Beam(longitudinal) = 0.7 X 1.2 X 25 Concrete Pile = 23 X 1 X 25	1.8 kN/m^2 7.5 kN/m^2 40 kN/m^2 21 kN/m^2 451 kN/m^2	DEAD LOAD
3.	Function of berth : Passenger berth	Truck Loading : B Uniform vertical Live Loading :10 kN/m^2	LIVE LOAD
4.	Displacement Tonnage = 20000 tonnes Velocity of vessel = 0.1 m/s g = 9.81 m/s^2 eccentricity coefficient = 0.51 mass coefficient = 1.6 softness coefficient = 0.95	Berthing Energy = 79.021 kNm	BERTHING LOAD
5.	Wind pressure :50 kg/m^2 shape factor = 1.5 length between perpendiculars = 155 m mould depth : 13 m Average light draft = 4	Windage area = 1639.125 Mooring force = 1229.344 kN	MOORING LOAD
6.	unit weight of sea water = 1.025 tonnes velocity of current = 0.26 g=9.81 m/s^2	Current force =35.316 N/m^2	CURRENT LOAD
7.	Base velocity of wind =31.11 m/s k1 = 0.92 k2 = 1.0 k3 = 1.0	Wind force = 534.243 N/m^2	WIND LOAD
8.	All the loads from 1 to 7 as above	dlbl+mooring+dlwc dlslab+dlbt+berthing dlbt+dlslab+mooring current+dlslab+berthing	LOAD COMBINATIONS
9.	apron width =35 m length between expansion joint = 34 bed slope =0 maximum pile height = 23 c/c distance between piles = 5 m beam MI = 1 column MI = 1	Maximum moment in column = 1415.526 kNm Maximum moment in beam = 1334.235 kNm	KANI'S METHOD

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10.	Factored moment in lx direction = 136127.5 kNm Factored moment in ly direction = 69452.764 kNm depth of slab = 0.3 m concrete mix = 30 diameter of bar = 12 mm length of slab : 7m breadth of slab : 5 m	x- direction spacing =90 mm no of bars =54 y-direction spacing = 190 mm no of bars = 37	DESIGN SLAB
11.	reinforcement calculated in the above step	slab reinforcement details is drawn	SLAB REIFORCEMENT
12.	breadth =0.8 m height = 1.2 m BM = 1334.235 kNm concrete mix = 30 steel = Fe500 diameter of bar = 25 mm	tension steel =6	DESIGN BEAM
13.	reinforcement calculated in the above step	beam reinforcement details is drawn	BEAM REINFORCEMENT
14.	Load on top of pile = 451.786 kN BM = 1415.526 kNm length of pile = 23.3 m diameter of pile(D) = 1m mix = 25	select a suitable chart from SP16.	DESIGN PILE
15.	$Pu/(fck..D^2) = 0.018$ $Mu/(fck..D^3) = 0.056$	$p/fck = 0.04$	CHART 60
16.	reinforcement calculated in the above step	pile reinforcement details is drawn	DRAW PILE

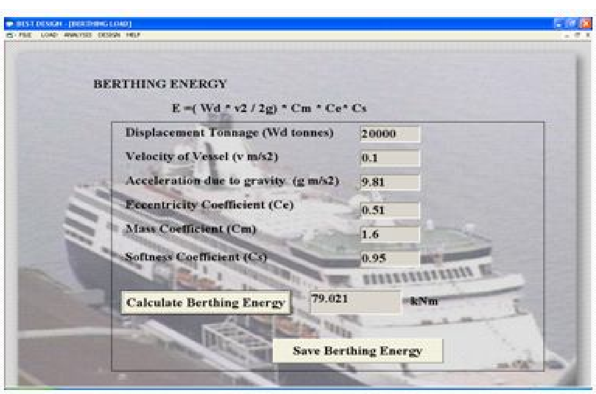

Fig.4. Load Calculation Form

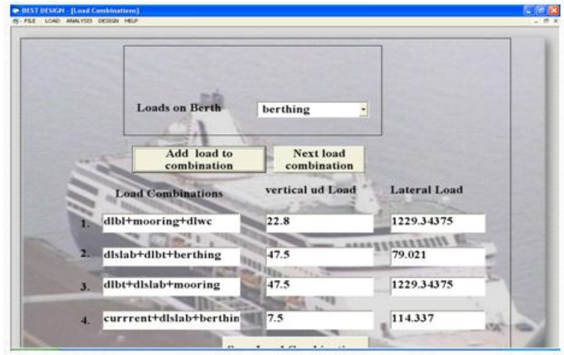

Fig.5 Load Combination Form

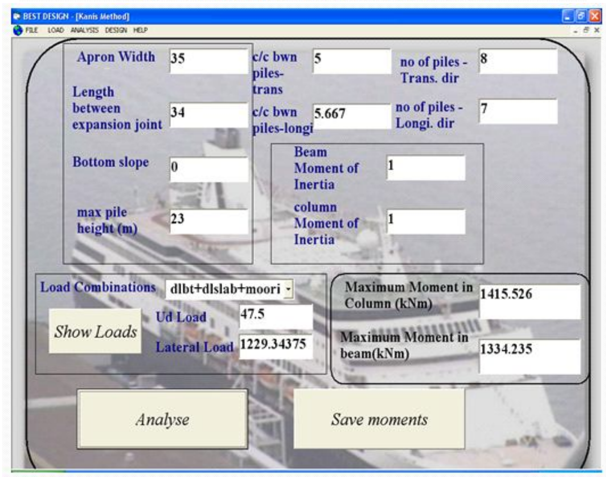

Fig.6. Analysis Form

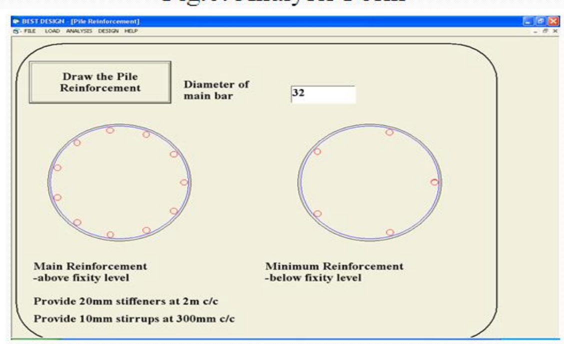

Fig.7. Design form

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